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RESEARCH STUDY OF A CO₂ LASER RADAR TRANSMITTER

SEMIANNUAL TECHNICAL SUMMARY REPORT

February 1968

Prepared by

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Semiannual Technical Summary Report
1 May 1967 through 1 January 1968

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ABSTRACT

Exploratory work on the behavior of dc and pulse excited CO₂ laser amplifiers has resulted in the design and construction of a prototype laser radar transmitter. It is capable of an output of 1 kW average power in a train of 10 μ sec pulses at a pulse repetition rate of 10 kc. This report summarizes the experimental results leading to the final design, outlines the design features and discusses initial tests of the performance of the completed device.

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I. INTRODUCTION AND REVIEW

This project is part of a program to develop a Doppler laser radar system. The transmitter for this system should provide an output stable in frequency to within several kilocycles and should have a geometrical form stable enough to project an output beam that is limited only by diffraction effects in the optics.

Consideration of various possible modes of operation for a laser radar suggested that a pulse Doppler technique be tried using trains of 10 - 20 μ sec pulses. The problem then was to produce such a pulse train in a controlled manner and at a reasonable efficiency with an average output power of 1kW.

At the beginning of this investigation an oscillator with an average power in excess of 1 kW had been operated in our laboratory using dc excitation of a flowing mixture of helium, CO₂ and nitrogen. A number of additional experiments using pulse-excited oscillators had suggested that efficiencies of energy conversion comparable to the dc-excited tubes might be attainable.

The first semiannual report on our work from 1 November 1966 to 1 May 1967 has already discussed in some detail our understanding of the energy dynamics of the CO₂:N₂:He system, together with the results of a number of experiments on both dc- and pulse-excited amplifiers. We may summarize briefly the results of those experiments as follows:

1. While pulse excitation of amplifiers leads to an enhancement of small-signal gain to between three and four times that observed in dc-excited tubes, this improvement disappears as the pulse repetition rate increases. A recovery time on the order of milliseconds, probably related to thermal diffusion, comes into play. Thus, while an increase in volumetric efficiency for the generation of individual pulses can be achieved by pulsing, the generation of a given average power takes much greater lengths of amplifier than the dc-excited case.

2. Dc-excited amplifiers are driven into saturation at flux densities of the order of 60 W/cm^2 for Gaussian-like beams.
3. Performance of a high gain amplifier is limited by self-oscillation which sets in when the small signal gain approaches 60 dB.
4. The efficient use of a dc-excited amplifier requires pulse repetition rates of the order of 10 kc, a rate governed by the transfer of energy between the excited nitrogen and CO_2 species.

As a result of these experiments we decided that a dc-excited system was the best choice for a first-generation device and built a breadboard model transmitter which consisted of a primary oscillator emitting some 20 W, a 12-m long buffer amplifier of 1 in. i.d. discharge tubes and a power amplifier of 20 m of 2 in. i.d. discharge. The pulse train was formed by focussing the 300 W output from the buffer amplifier and mechanically chopping in the focal plane of the optics. A final output power of up to 435 W was measured on this device when operated at a pulse repetition rate of 12 kc.

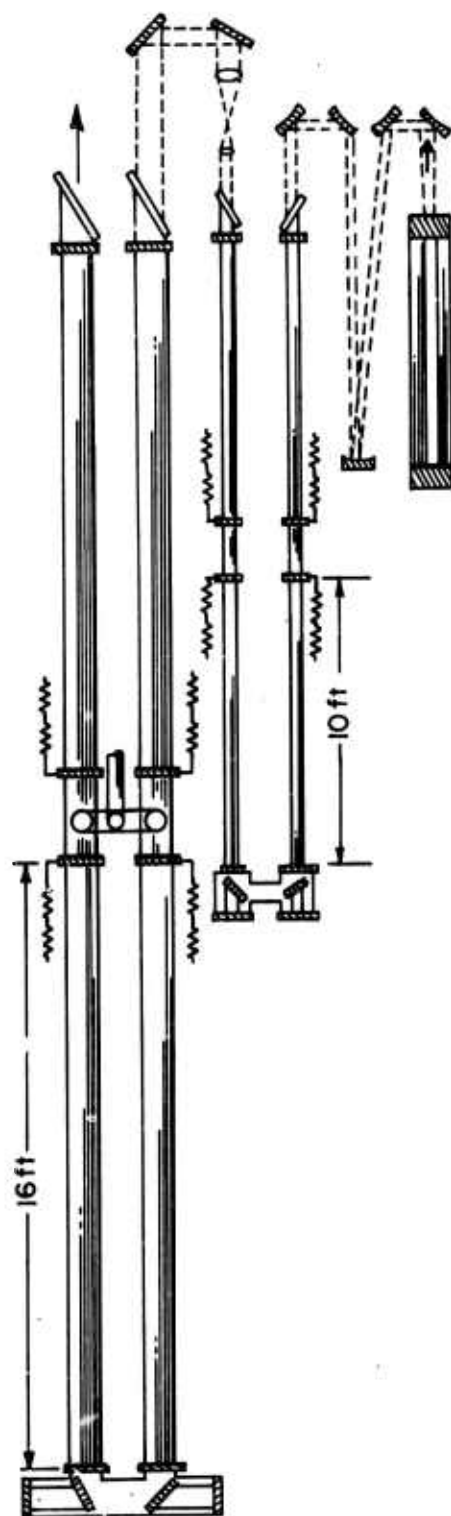
Our work since that time has been quite varied. To begin with, several attempts were made to improve the geometric form of the output from the breadboard model by changing the beam collimation in the buffer amplifier. While this was partially successful, the form of the output beam was evidently limited by the quality of the NaCl windows used. No significant increase in power was observed. In all these experiments the pulse train amplitude was found to be strongly modulated by the power amplifier. This pointed to the need for current stabilization of the discharge tubes: as a consequence we designed and built such a device.

In parallel with these latter experiments we designed and built a prototype transmitter designed to give the full 1 kW average power output. This equipment has been in use since December 1st, 1967, with steadily improving output. At this time we have measured 900 W average power in the 10 μ sec pulse train, together with a background of 350 W of spurious oscillation in the power amplifier. Current stabilization should suppress the background and allow generation of the full 1 kW.

II. TRANSMITTER BREADBOARD MODEL

The first high-power transmitter which we built (Fig. 1) consisted of a 2 m, 1/2 in. i.d. oscillator, a folded 12 m section of 1 in. i.d. buffer amplifier, NaCl modulator optics, and a 20 m section of 2 in. i.d. power amplifier. The discharge tubes were water cooled. The oscillator was run from a 30 kV supply with a 150 K Ω ballast at currents between 30 and 50 mA. The various sections of the amplifiers (four sections in the buffer amplifier and four sections in the power amplifier) were all fed in parallel from a 30 kV supply with multiple ballast resistors. Typical current levels were 60 mA for the individual buffer amplifier sections and 90 mA for the power amplifier sections. A 5 percent voltage ripple at 360 cps produced a 20 percent peak-to-peak current ripple in the amplifier tubes as a result of the negative impedance characteristic of the discharges.

The gas flow to the discharge tubes in the power amplifier entered at each end of the sections and was pumped out at the center by a 100 cfm pump. In the buffer amplifier this flow pattern was reversed with a 15 cfm pump attached to each end of the assembly. Three separate gas flow controls were provided for the oscillator, the buffer amplifier and the power amplifier respectively. Considerable attention had to be paid to the symmetry of both the electrical ballasting, the gas flow pattern and the water cooling flow pattern, to ensure easy starting of all the discharges in parallel, their stability while changing gas mixture and tube current and their stability over long periods of operation. From the viewpoint of safety, it is desirable to have the end electrodes of all amplifier sections at ground potential. As a consequence, only one ballast can be introduced for each tube. This makes it necessary to introduce an unexcited section of tube between each discharge path. We find that a 10:1 ratio of discharge length to separation length is adequate to ensure a stable discharge pattern.



400 WATT BREADBOARD TRANSMITTER (SCHEMATIC)

FIGURE 1

The optics in the oscillator consisted of a spherical back mirror (radius of curvature four meters) made from gold coated silica together with an uncoated germanium flat for the output reflector. The latter was set in an aluminum housing and water cooled. The mounts for both mirrors were adjustable in angle; in addition, one end mount could be moved to allow length tuning. The output from this device was over 20 W when run without internal irises. The mode structure was usually in a spatial mode with two lobes. Introduction of an iris at the output end gave a single lobe output, but at cost of a power reduction to some 15 - 17 W. Mode jumping still occurred, but this could be eliminated for a period of the order of one minute by adjusting the resonator length. While this oscillator was adequate to perform the initial experiments on the amplifier, it was obviously not good enough for testing of the final transmitter design.

The beam divergence at the oscillator was approximately 3×10^{-3} radian. In order to recollimate the beam for projection through the buffer amplifier, a single concave spherical mirror (5 m focal length) was used at close to normal incidence. It was set 5 m from the exit window of the oscillator. The amplifier beam observed as it emerged from the buffer amplifier filled the full aperture and showed a concentric ring structure characteristic of reflection from the tube walls.

The buffer amplifier had NaCl Brewster windows at each end with the full 12 m folded into two 6 m sections by using a pair of gold coated silica mirrors set up internally to the amplifier with two-angle controls on each surface. These controls could be operated from outside their housing.

Apart from the size of the structure, and the details of the mirror controls, the design of the power amplifier was little different from the buffer stage amplifier. In this case, however, the turnaround mirrors were made of gold plated sapphire to minimize thermal distortion of the optics. In fact, no distortion effects due to heating were detected in either amplifier. (One of the silica mirrors, 1/8 in. thick, in the first collimating assembly did distort and was replaced by a gold-plated stainless steel mirror.)

The modulator optics consisted of a pair of $f/4$ NaCl lenses with 4 and 8 in. focal lengths. No attempt was made to eliminate the Fresnel reflection from the lens surfaces. As first set up, two gold-plated pyrex mirrors were set one on each side of the focal plane of the system, and approximately 2 in. from the focal point. This proved to be a mistake --- the second mirror surface, which was subjected to pulsed heating, deteriorated by developing spherical bulges in the gold plating, while the first surface finally broke. A more successful arrangement took the beam directly through the modulator before letting it strike the surfaces of the turnaround mirrors.

The most difficult task in the alignment of the entire system proved to be control of the beam as it passed through the buffer amplifier. The process was greatly hampered by our inability to observe the beam directly as it approached the turnaround mirrors. The 1 kW transmitter was designed with this difficulty in mind.

Figures 2 and 3 show two views of the system. Figure 2 shows the back end of both the power amplifier and the buffer amplifier. The mounting and controls of both pairs of turnaround mirrors can be seen partly. The vertical mounting of tubes was done to conserve space, but has the disadvantage that dust can collect more easily on the lower mirror in the turnaround assembly. Figure 3 shows the somewhat involved arrangement at the operating end as it was first set up. The output end of the oscillator can be seen at bottom center. The adjustable mirrors form part of the first collimator. The original arrangement of the modulator lenses can be seen clearly at the lower right.

The output for the entire system was measured by a flowing water calorimeter and its temporal behavior was observed with an Au-doped Ce photoconductive detector operating at 77° K.

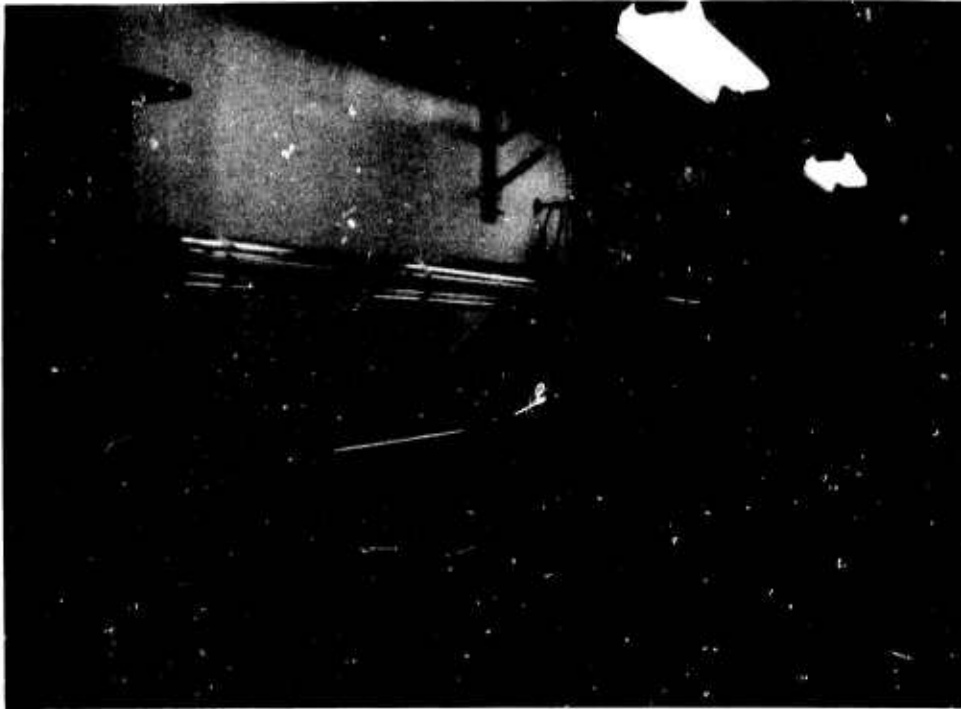


Fig. 2 The 400 W Transmitter - Rear View

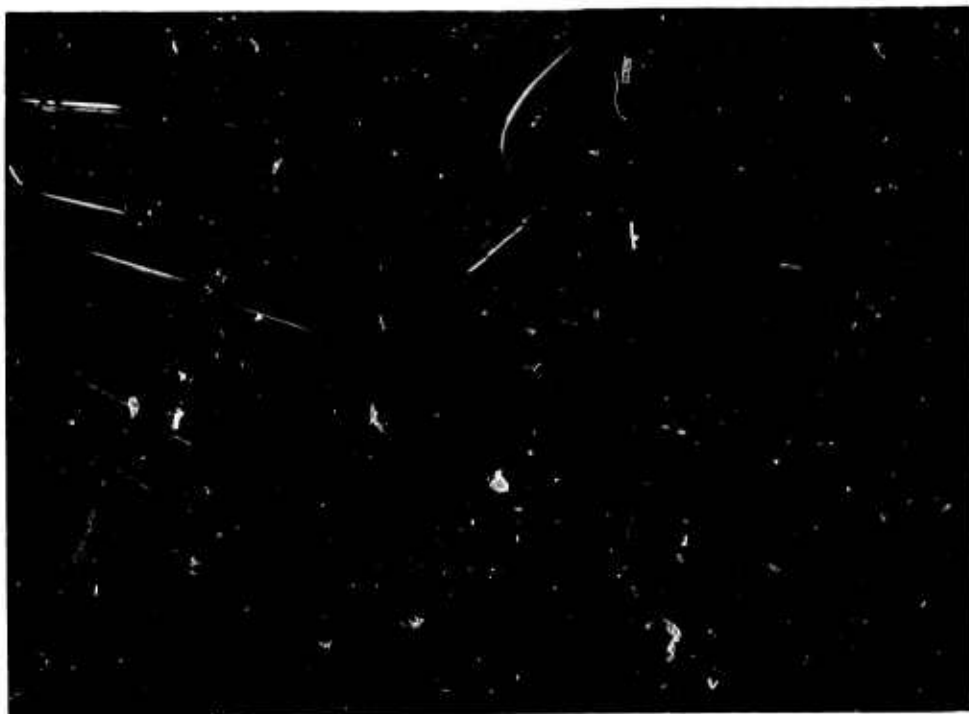


Fig. 3 Front View of the 400 W Transmitter Showing the
Primary Oscillator, Modulator Optics and Amplifier Ports

Figure 4 shows the form of the final output pulse train running at 12,000 pps and an average power near 350 W. In this particular experiment the pulse-to-pulse stability was unusually good. A more typical output (Fig. 5) on a slower sweep scale, shows large low-frequency fluctuations traceable to the oscillator, but augmented by the amplifier. Together with these there appears a higher frequency variation associated with ripple in the amplifier currents.

The physical form of the output beam showed a fine structure originating in the NaCl Brewster windows together with a larger-scale pattern which followed the form of the output from the buffer amplifier. As the gain of the power amplifier was increased, the form of this pattern remained unchanged, but experienced a general brightening. This encourages us to believe that actual beam distortion by the amplifier discharge itself will not be a major problem in beam control.

Our earlier experiments on small-signal gain and gain saturation had led us to expect 500 W from this breadboard device. In fact, we obtained only 400 W when the oscillator was running in a mode with a single lobe and 435 W when the oscillator mode had two lobes. These data have resulted in an increase in size for the power amplifier section in the design for the 1 kW transmitter.

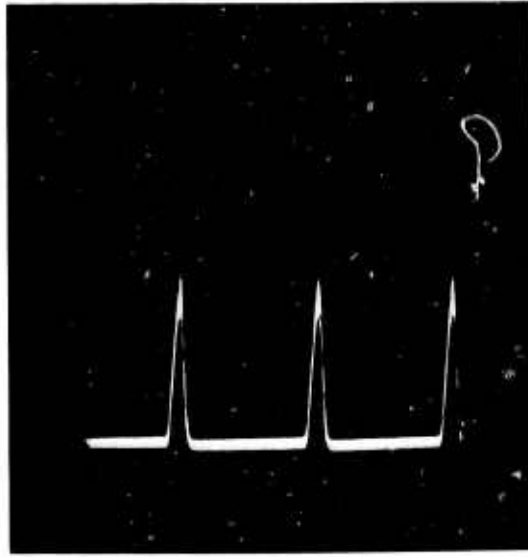


Fig. 4 Transmitter Output Pulse Train with 12,000 Pulses per Second

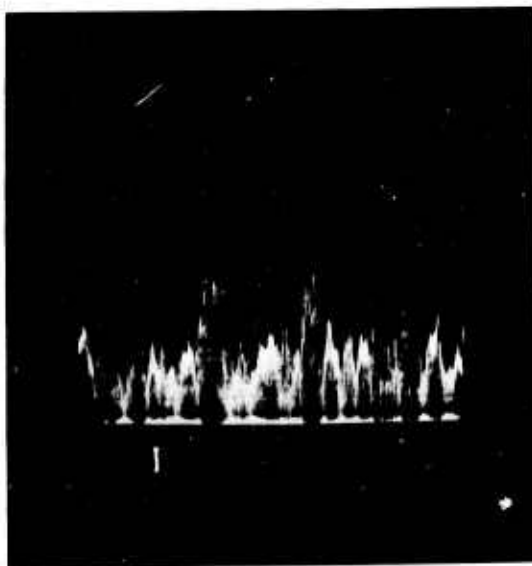


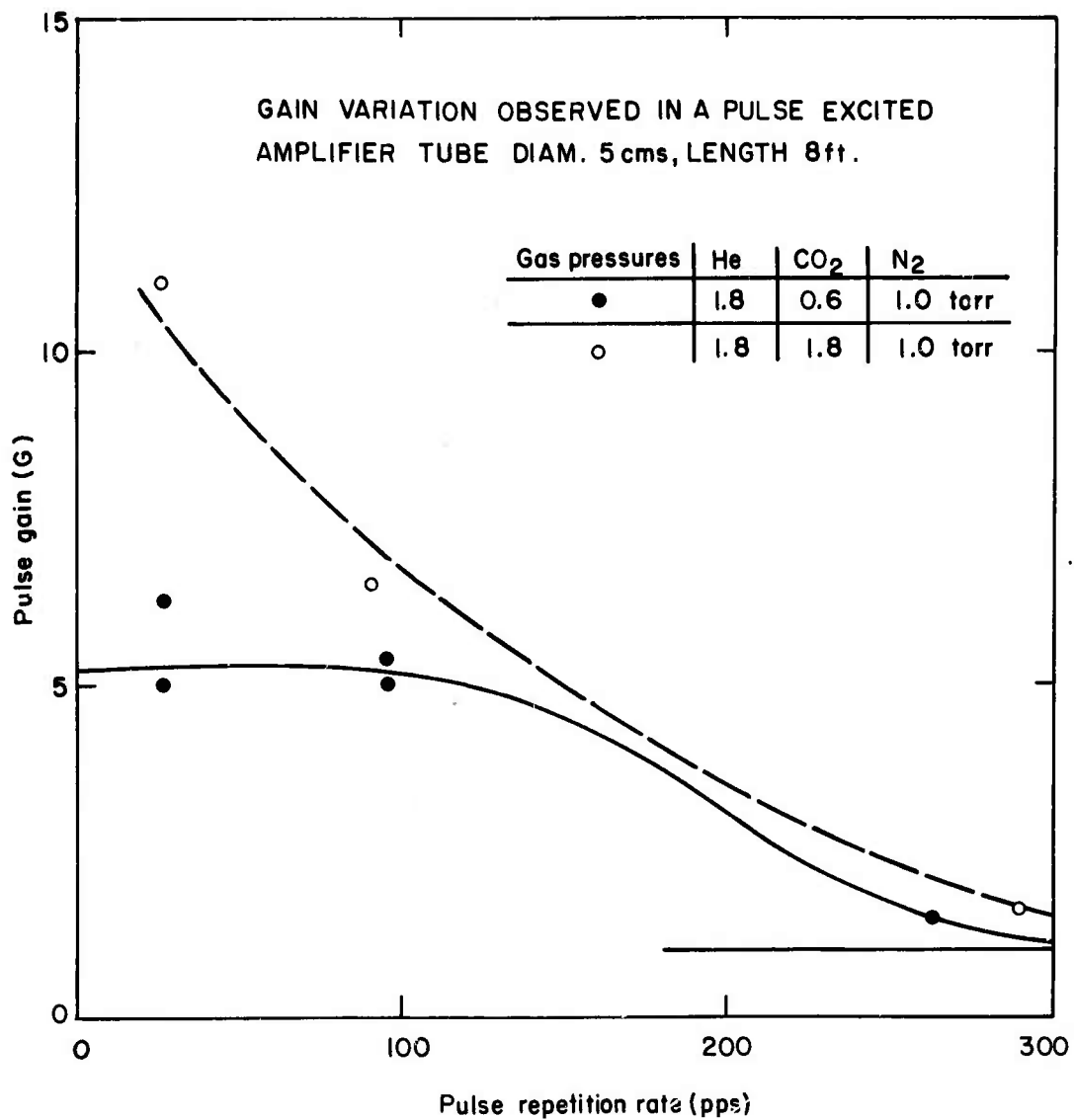
Fig. 5 Low Frequency Modulation of the Output Pulse Train
Caused by Oscillator Instability and by Amplifier Gain
Modulation

III. EXPERIMENTS ON PULSE EXCITATION

In the first semiannual report we discussed the enhancement of optical gain which could be achieved by electrical pulse excitation of a 2 cm i. d. amplifier tube. It was found that the small-signal gain was some three times as great as that observed in the same amplifier under dc excitation, but that this gain decreased as the repetition rate was increased. Reanalysis of that data indicated that the gain enhancement dropped by one-half of its original value for a repetition rate slightly over 300 pps. This could be interpreted as the result of a recovery process governed by a 3 msec recovery time.

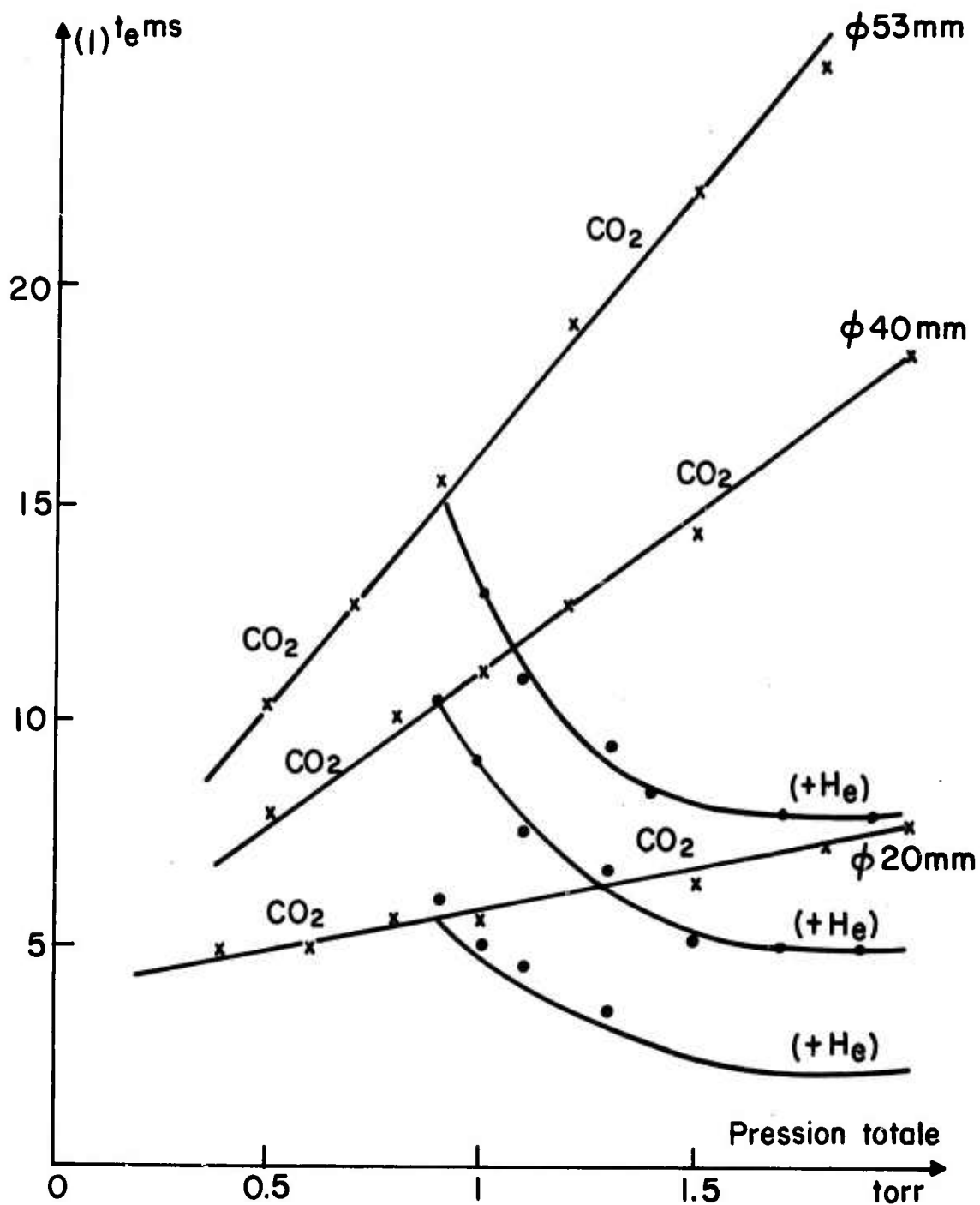
A similar measurement was carried out using one 2 1/2 m section of the 2 in. i. d. amplifier. The results, indicated in Fig. 6, show a gain of 3 dB/meter at low repetition rates for a gas mix which would normally show 1.1 dB/meter gain with dc excitation. While the data is too sparse to be definitive, it appears that a 5.5 msec recovery time is appropriate for this tube and gas mix. By increasing the CO₂ content of the mixture, a considerable increase of gain was observed at low rates, without much change at rates beyond 100 pps. Time constants in the range of milliseconds are very suggestive of thermal diffusion over dimensions of several centimeters at gas pressures of several torr, and this explanation was suggested in our last report. A similar interpretation has now been proposed by Van Lerberghe, et al.* to explain their own experiments on pulse-excited oscillators. In these latter experiments, the total energy output from a pulse excited oscillator was measured for each of a pair of electrical input pulses as a function of the time delay between pulses. For large pulse separation the outputs were equal, but as the separation decreased the second pulse output also decreased. The recovery time defined from these experiments was found to increase linearly with CO₂ pressure and to be reduced by the addition of helium. Increase of helium beyond 0.8 torr had little effect (Fig. 7).

* Van Lerberghe, et al, "Étude du temps de recouvrement du laser à gaz carbonique excité par décharges impulsionnelles," C. R. Acad. Sc. Paris, t. 265, 359 (7 August 1967).



DEPENDENCE OF SMALL-SIGNAL GAIN ON THE REPETITION RATE IN A PULSE.

FIGURE 6



DEPENDENCE OF RECOVERY TIME OF A DOUBLE PULSE OSCILLATOR ON TUBE DIAMETER AND ON TOTAL GAS PRESSURE FOR PURE CO_2 AND $CO_2 : He$ MIXES.
(after Van Lerberghe et al¹)

FIGURE 7

Figure 8 attempts to put together our own data on pulsed amplifiers with those derived from the pulsed oscillator work. While the times are consistent, this may be to some extent fortuitous, considering the few data points in one case, and the clearly nonexponential form of the oscillator recovery measurements. In any case, they do not follow the simple quadratic dependence on tube diameter that would be expected from a geometrically scaled temperature recovery.

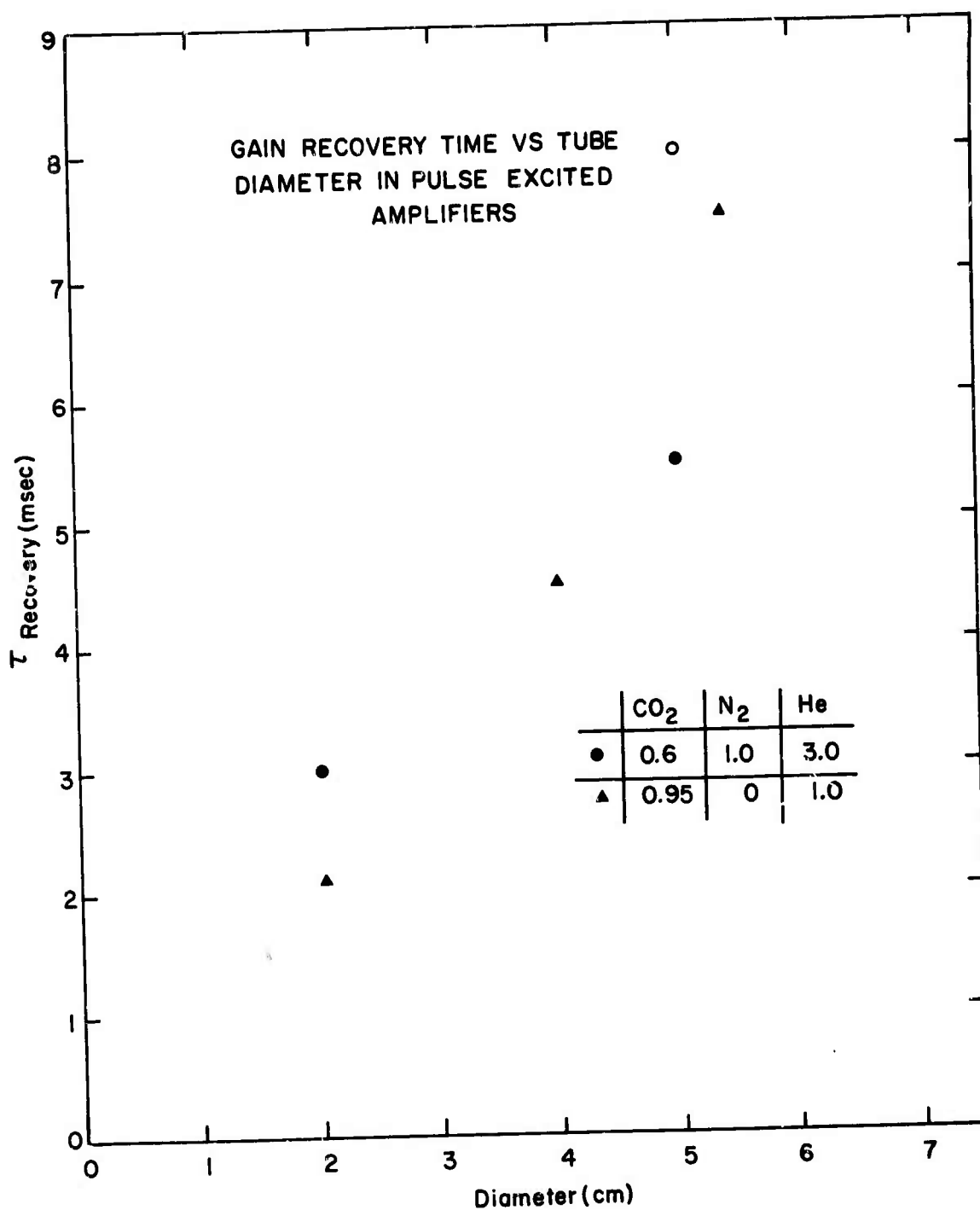


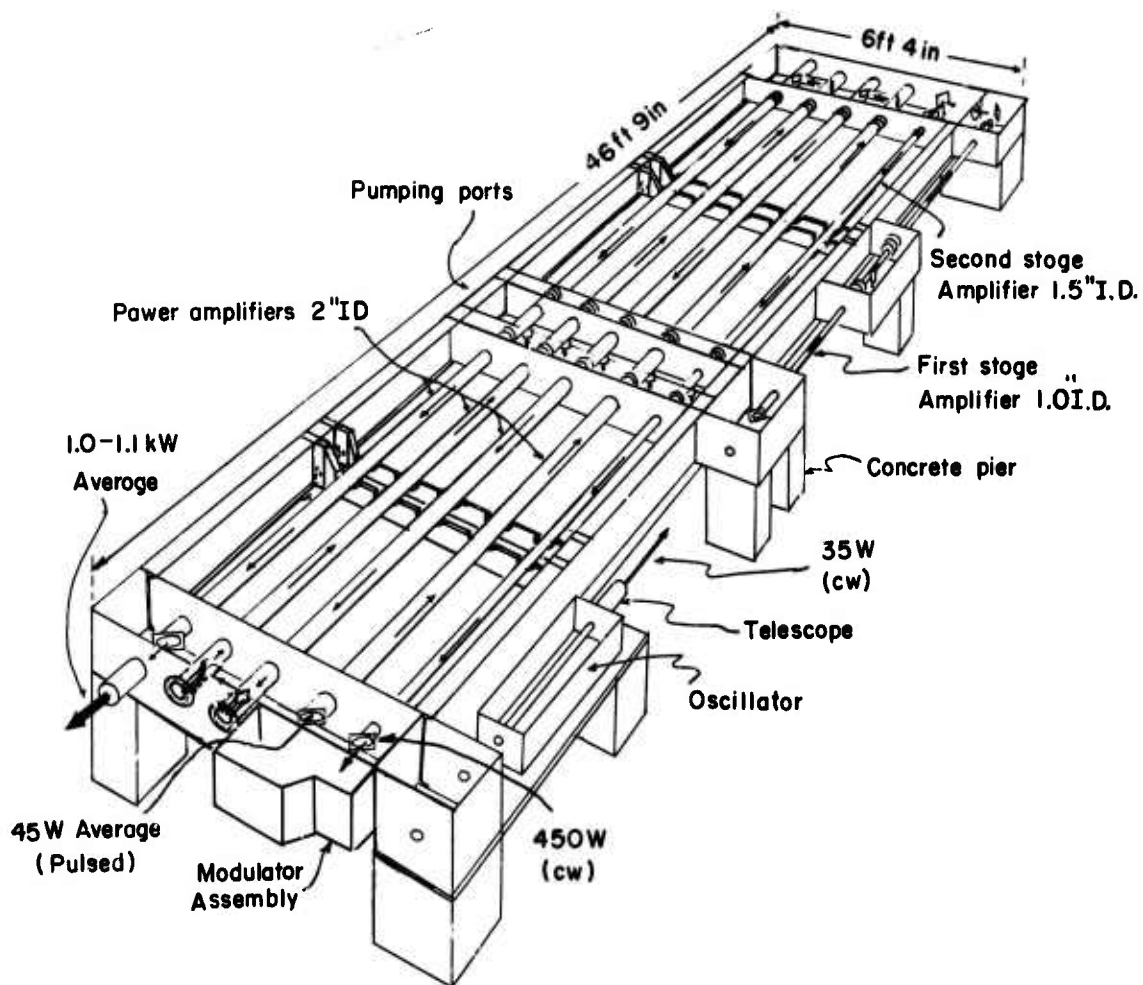
Fig. 8 Dependence of Recovery Time on Tube Diameter
(Composite Data)

IV. 1 kW TRANSMITTER DESIGN

The design and layout of our prototype transmitter is shown in Fig. 9. It is quite similar to the breadboard model on which we performed our high-power measurements. The differences appear in the size, the quality of the optics, and design features to improve the alignment and form of the beam. The 35 W output from the primary oscillator is collimated by a reflective telescope and passes through two stages of amplification before reaching the modulator. Each stage consists of a separate pair of discharge tubes with Brewster angle windows of NaCl at each end. The first stage provides six meters of 1 in. i. d. discharge separated by an unexcited central section of 0.75 m. The second stage gives 12 1/2 m of 1 1/2 in. discharge with a 0.75 m central section. In both cases the new gas mix enters through the anodes at each end of the amplifier and is pumped out at the center. This design was chosen to do two things:

1. To allow examination of the beam after it has passed through the 1 in. i. d. amplifier.
2. To introduce more flexibility into the structure of the buffer amplifier.

Our analysis indicated that the use of a 1 in. i. d. discharge throughout the entire length of the preamplifier would give approximately 550 W at the modulator, where we can expect only 450 W from the present design. It is clear that efficient use of the final power amplifier stage requires as high a power level as possible at the input end. Consequently, the smaller choice of tube diameter would enhance the final output. However, our past difficulties in beam alignment in 1 in. tubes led us to choose a larger-diameter amplifier for the second stage to minimize the effects of wall reflections.



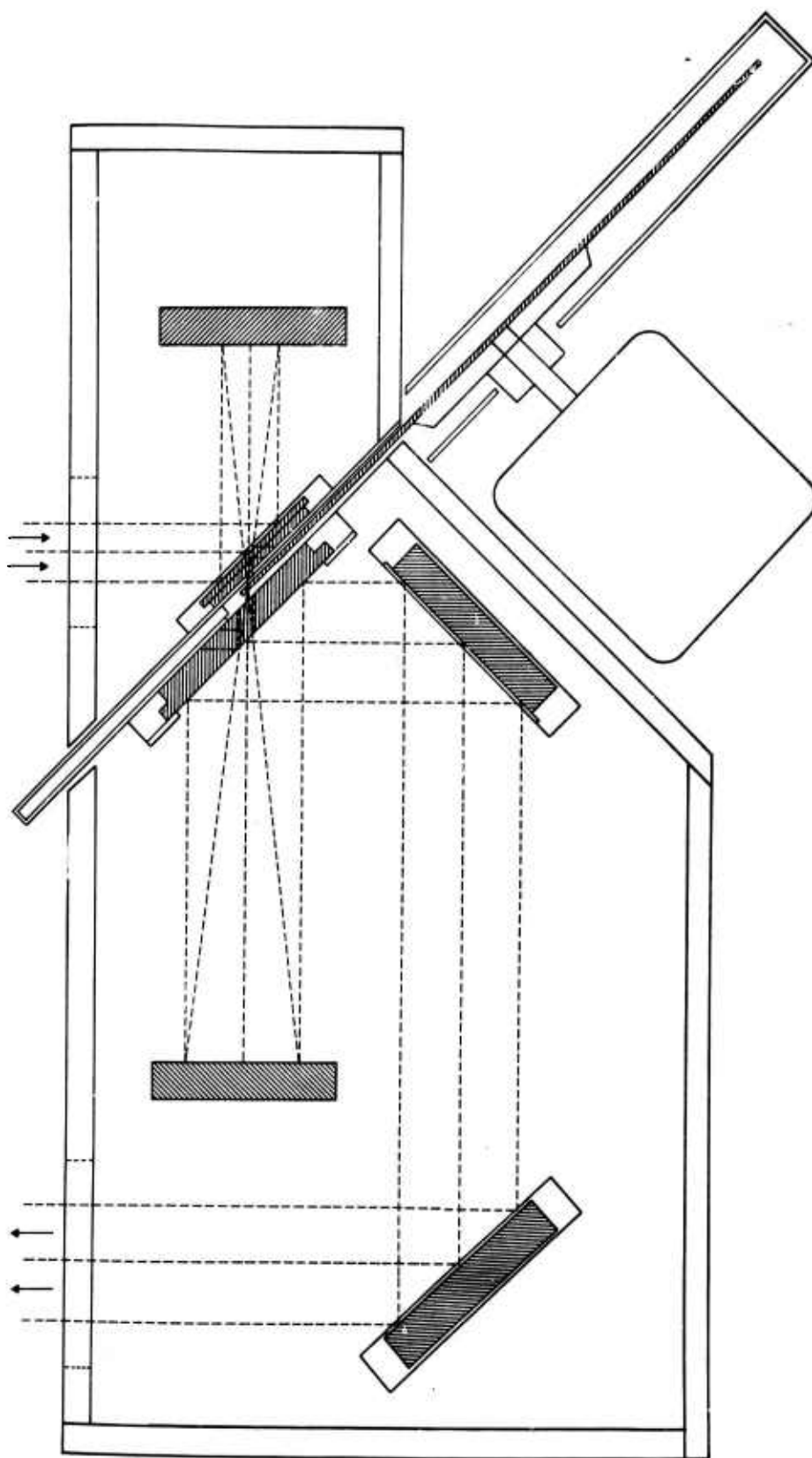
PROTOTYPE 1 kW TRANSMITTER DESIGN.

FIGURE 9

A novel design for the modulator optics introduces on-axis parabolic focussing mirrors in place of the NaCl lens assembly used in our previous experiments. This is done to eliminate a specular reflection from the modulator back into the power amplifier, an effect which increases the possibility for spurious oscillation in this latter amplifier. Figure 10 shows the optical arrangements in more detail. The main design feature is a pair of perforated plane mirrors set at 45° to the optical path and spaced out to allow a chopper blade to pass through the confocal point of the parabolic mirrors. The focal lengths of these latter mirrors have been chosen to give a twofold expansion of the beam as it passes from the second-stage amplifier into the power amplifier.

The power amplifier itself consists of four runs of 2 in. i. d. tubing with each run having 12 1/2 m. of discharge path and a 0.75 m central unexcited section. The total amplifying length is thus 50 m. The entrance and exit Brewster windows are again of NaCl. This material has been used throughout because of its availability and relatively low cost. However, we are considering its replacement by KCl in order to increase the useful life of the windows. At the end of each of the four runs, a pair of gold-plated copper mirrors is used to reverse the direction of the beam. One of the mirrors is housed in a preset aluminum mount, while the second member of the pair is set in a mount whose attitude can be controlled by micrometer adjustment from the outside of the amplifier housing. Figure 11 shows one of these mirror pairs.

The gas feed to the power amplifier is again accomplished by injection at the end anodes of each run, with a balanced flow towards the output pumping post at the center section. A single 300 cfm pump is used to evacuate all amplifier tubes with pneumatically controlled valves housed below the one end section of the power amplifier. This assembly can be seen partially in Fig. 12.



REFLECTIVE MODULATOR DESIGN

FIGURE 10



Fig. 11 Turnaround Mirror Assembly in the Power Amplifier

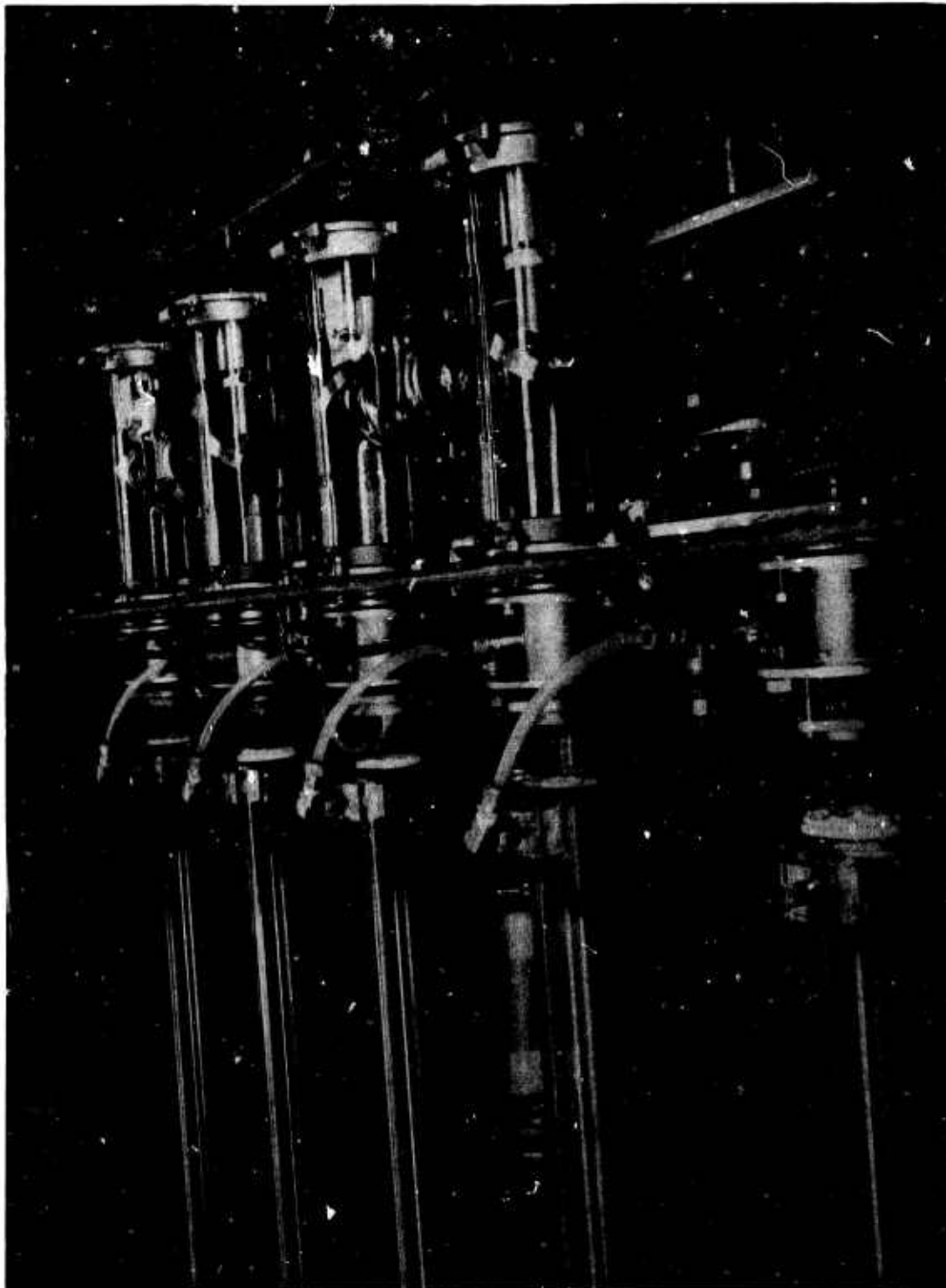


Fig. 12 View of the Back End Assembly of the Transmitter
Showing Mirror Housing and Vacuum Control Valves

The entire amplifier assembly is held together in an aluminum and steel frame. It was designed both to provide a stable and dependable mounting for the optics and to be of a form to allow disassembly and transportation of the transmitter with as little difficulty as possible. There are three aluminum boxes, one at each end to house the mirrors and window mounts and one in the center to hold the cathode assembly and exit pumping ports. These boxes are connected by steel H beams in 10 ft sections spaced out by intermediate cross-frames which provide a cradle support for the amplifier tubes. Figure 13 shows this assembly and gives an over-all view of the complete device. The primary oscillator appears at the lower right of this view. The entire frame is mounted on molded rubber vibration pads set on twelve concrete piers and set so that the central plane of the optics is 50 in. above the floor level. The space underneath is used to house the high voltage supplies and current stabilization equipment.

Two separate power supplies are used to excite the amplifier. A 32 kV, 275 mA supply activates the first and second stage amplifiers, while a larger 32 kV, 750 mA unit provides the current for the main power amplifier. Each supply is a simple three-phase rectifier circuit giving a 5 percent voltage ripple at 360 cps. In our initial tests on the transmitter we have used 125 k Ω resistive ballasts with each amplifier discharge section. These ballasts are about to be replaced by an array of electronic ballasts with effective impedances of several M Ω . The use of two independent power supplies makes for a more flexible use of the equipment.

As originally designed, the gas for all amplifier sections was mixed at one control station. While this arrangement was adequate, it proved awkward in sequential starting of all three amplifiers. We now have one gas control station for the first and second stage amplifiers and a separate one for the power amplifier. The controls for the power supplies and gas flow are shown in Fig. 14.

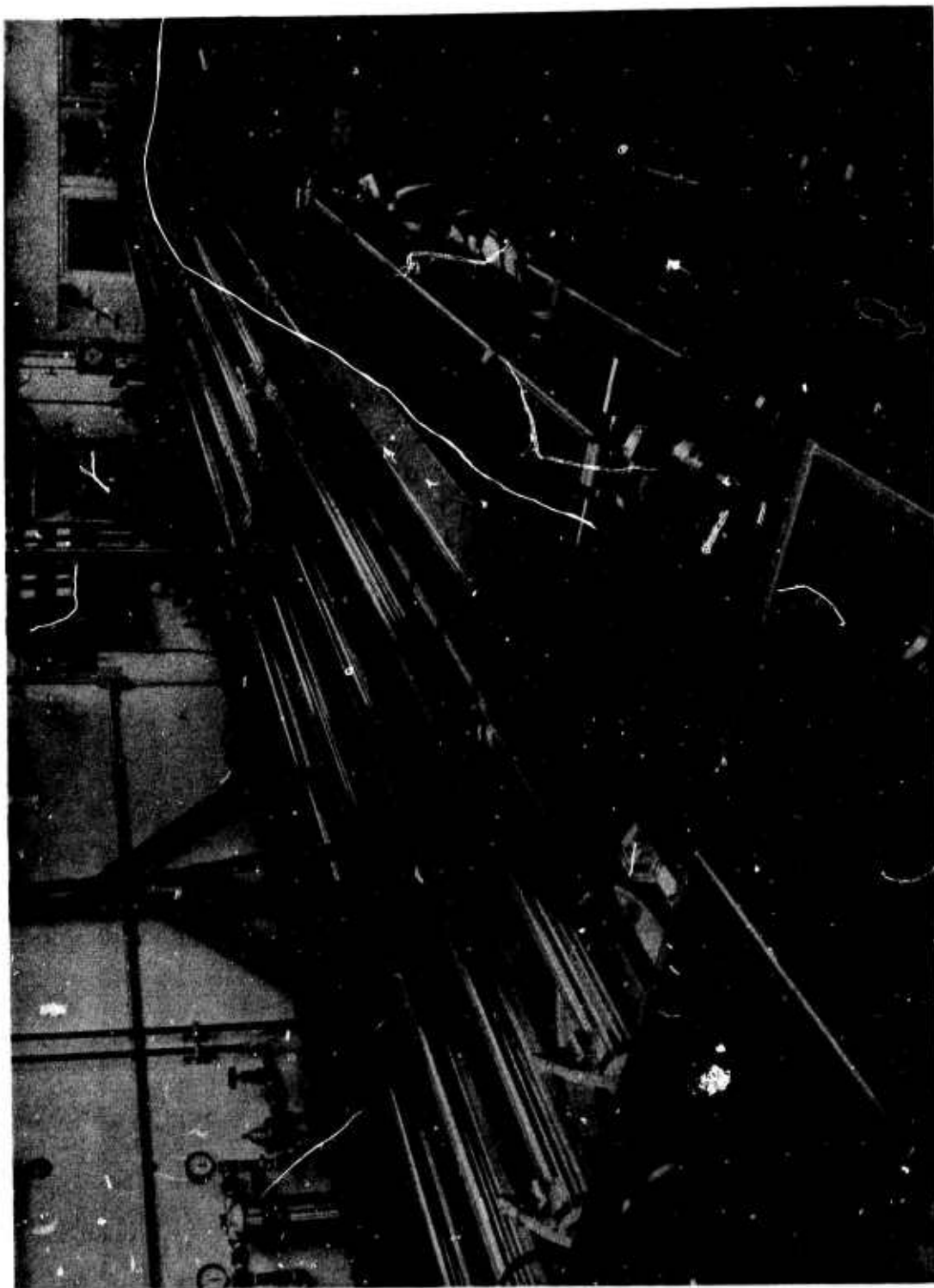


Fig. 13 Over-all View of the 1 kW Transmitter

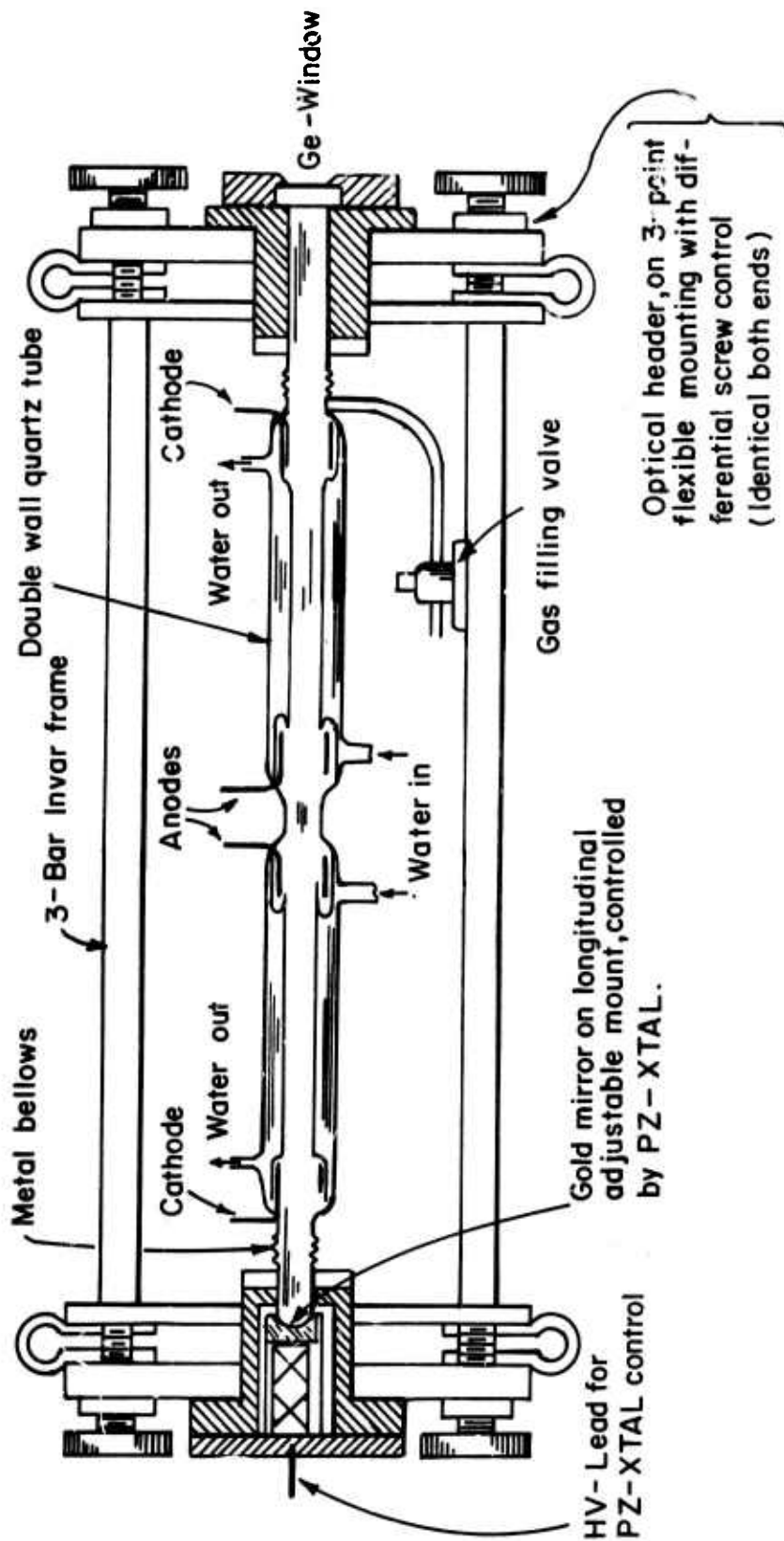


Fig. 14 Gas Flow and Power Control Station for the Transmitter

V. OSCILLATOR DESIGN

In order to test the transmitter amplifier, we are using as a primary signal source an oscillator built in connection with our program on frequency stabilization of CO_2 laser oscillators. Figure 15 shows this device. Adjustable end plate mounts are held by a three-bar invar frame to give a 2.1 m separation of the reflectors. The actual discharge section consists of 1.3 m of 12 mm i. d. quartz tubing separated into two parts by a 0.25 m central section. One reflector is a gold-coated spherical mirror set in a holder whose length can be adjusted by a piezoelectric device. The output reflector is a germanium flat, coated on one side to give 80 percent reflectivity at $10.6\ \mu$, and anti-reflection coated on the other surface. A 3/8 in. dia. iris is set in front of the spherical mirror. The discharge section is water cooled and is attached to the end sections by flexible metal bellows. When in use, this oscillator is sealed off from its gas supply system having been prefilled with a mix of CO_2 , N_2 , He and Xe gases. The output, which is usually in excess of 35 W, does not decrease more than 20 percent in a day's operation, after which it can be refilled.

At the time of writing, no device has been introduced to hold the polarization fixed: variation of this polarization, combined with the use of Brewster angle windows at six points in the amplifier path, results in considerable fluctuation in the final amplifier output.



PRIMARY OSCILLATOR DESIGN

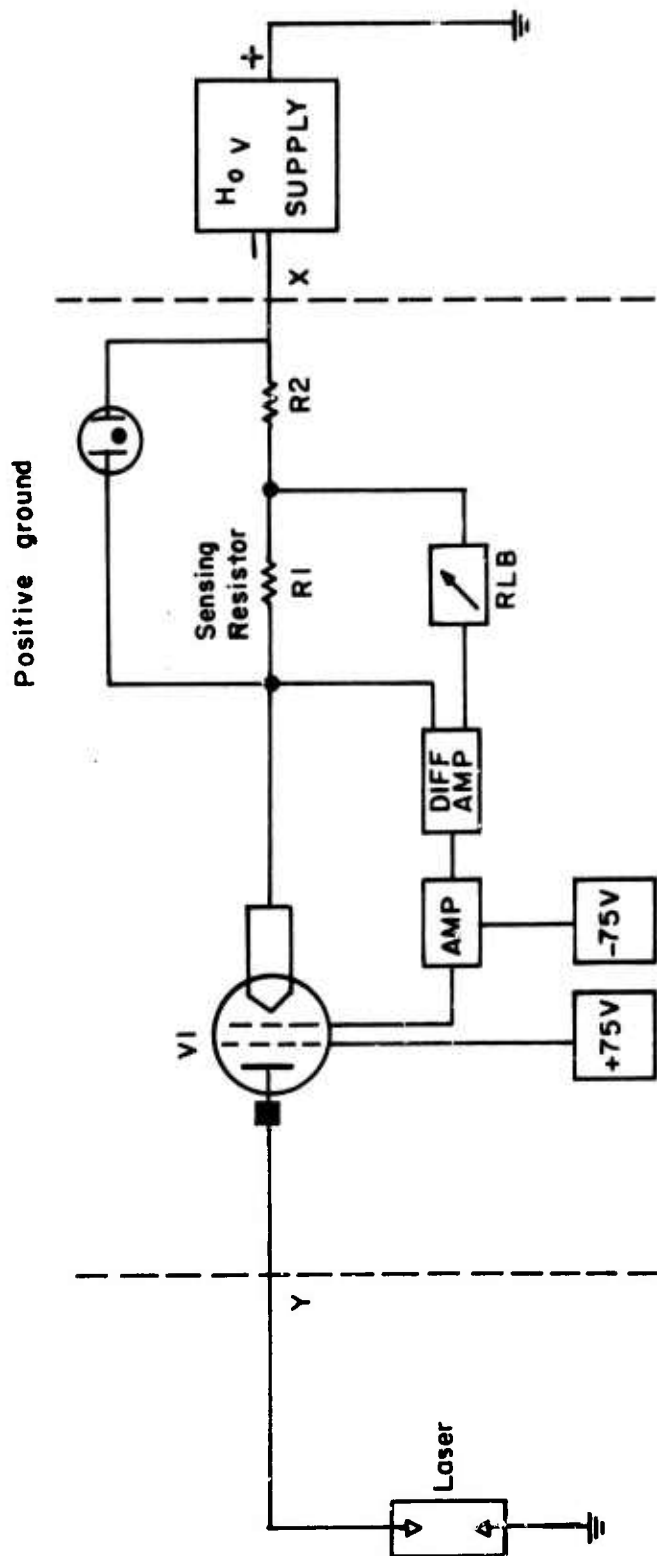
FIGURE 15

VI. CURRENT STABILIZATION

Under normal operating conditions, each discharge tube in the amplifier array has a negative resistance characteristic with an effective impedance of between $-40\text{ k}\Omega$ - $60\text{ k}\Omega$. At an operating voltage of 20 kV across the discharge and a 10 kV voltage drop across an accompanying $120\text{ k}\Omega$ resistive ballast, a 5 percent voltage ripple (1500 V) will result in a current ripple of 20 mA on an average current of 80 mA , i.e., a 20 percent ripple. This ripple is reflected in the amplifier gain coefficient and results in a severe modulation of the output signal. In order to overcome this difficulty, we have built an electronic ballast which can operate with an over-all voltage drop of 4 kV and provide an output current stable to one part in 500 when a voltage variation of 5 percent is applied to the ballast and discharge tube combination. Figure 16 gives a block diagram of this device.

A feedback-stabilized difference amplifier amplifies an error signal produced by comparing the voltage across a sensing resistor with that of an adjustable reference voltage. The output of the amplifier controls the grid voltage of a tetrode in series with the laser and high voltage power supply. The feedback and gain are arranged so that the effective output impedance of the ballast is $10\text{ M}\Omega$.

The electronic ballast has several advantages over conventional resistive ballasts, one of which is the ability to vary discharge current linearly from zero through maximum. Also, the electronic ballast requires generally much less voltage drop for a given current; hence, less power dissipation, smaller power supplies, and lower supply voltages result. The ballast compensates for power supply ripple as well, again decreasing the demands for quality and capacity in the high voltage supply.

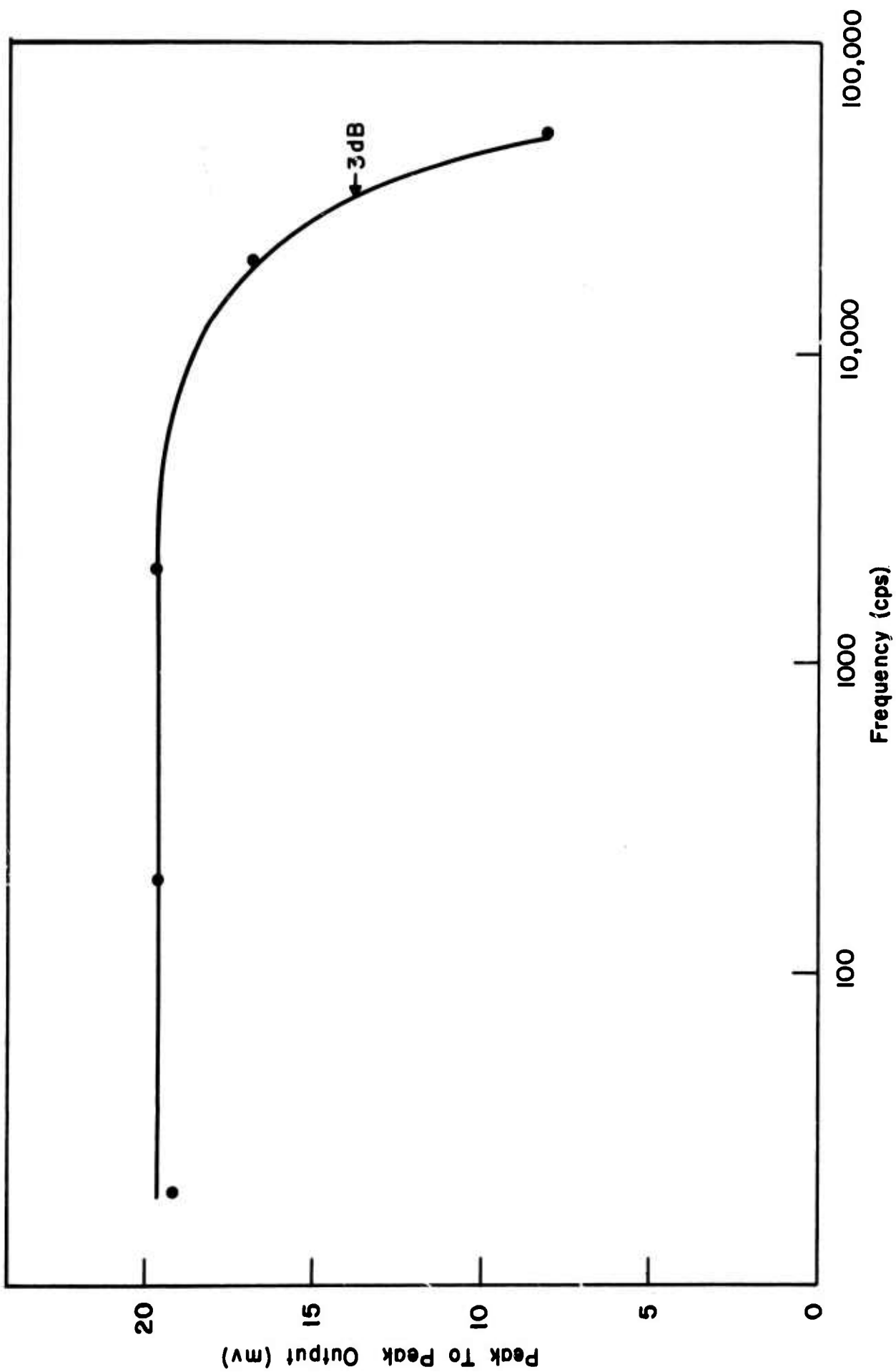


ELECTRONIC BALLAST CIRCUIT (SCHEMATIC)

FIGURE 16

The frequency response of the stabilizer (Fig. 17) is essentially flat from dc to 5 kc and is down 3 dB at 30 kc, which indicates that it can handle voltage and discharge fluctuations adequately up to some 20 kc.

Our experiments on pulse excitation indicate that gain buildup and decay takes place in times of the order of 100 μ secs or longer, having to do both with energy transfer between excited nitrogen and CO₂ molecules and with thermal diffusion rates. These processes will tend to stabilize the gain against variations more rapid than 10 kc. Thus we can expect that those current fluctuations at frequencies greater than 20 kc will have little effect on the amplifier gain characteristics.



FREQUENCY RESPONSE OF 60 mA ELECTRONIC BALLAST CIRCUIT

FIGURE 17

VII. TRANSMITTER PERFORMANCE

Apart from the more mundane difficulties of gas leaks, water leaks and high voltage breakdowns, the operation of the transmitter has proven to be a relatively simple matter. Up to this point we have been using our original modulator optics with NaCl lens, and have had only resistive ballasts connected in series with the discharge tubes.

We began our measurement with an oscillator output of less than 20 W and with the NaCl optics previously used in the 400 W bread-board model transmitter. After initial tests on the discharges and tests at output levels in excess of 1 kW, the Brewster windows were replaced by new material. Over the same period the oscillator output has been increased to over 35 W by improvement of the reflectors and gas mix.

The first major difficulty to appear was self-oscillation of the power amplifier section. This arose in part due to Fresnel reflection from the modulator lens surfaces, from backscatter at the modulator blade and to reflections at edges in the power amplifier itself. This output was measured as high as 550 W, and as much as 500 W with the low reflectance absorbers placed at each end of the amplifier. This spurious background has been reduced to 350 W by the introduction of low-reflectance irises at each turnaround mirror pair. The power amplifier was designed specifically to keep the small-signal gain low enough to suppress such oscillations. The remaining current ripple, however, produces peak gains which are probably in excess of 60 dB. We believe that the introduction of current stabilization will result in a background oscillation level of less than 50 W.

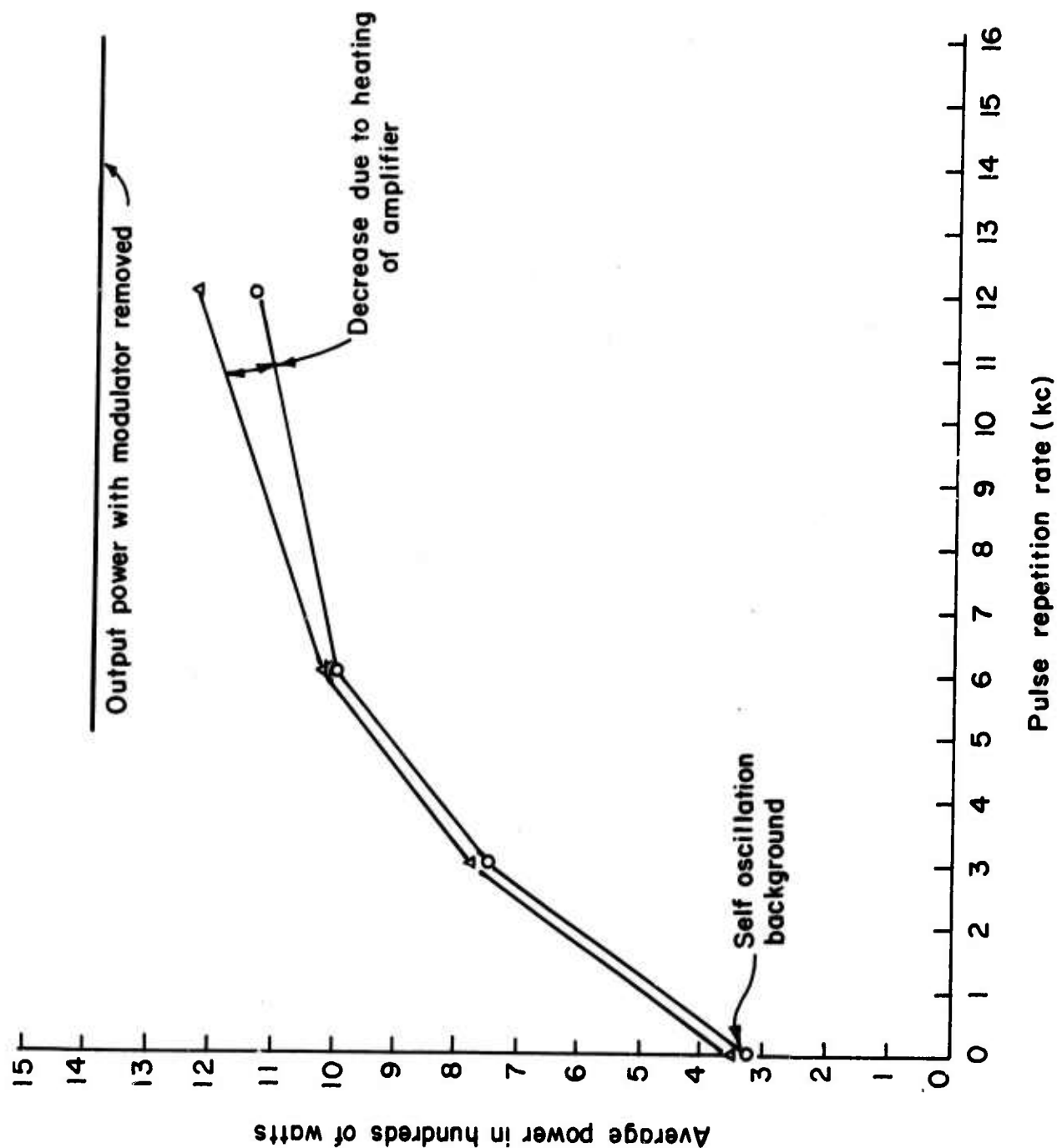
The second difficulty appears at the output of the second-stage amplifier. While the measured output is indeed over 400 W, only 250 W

emerges over the central 1 in. dia. of the exit aperture that is used by the modulator optics. As a consequence, the first stage of the power amplifier is operating as a thoroughly unsaturated amplifier with a resultant low efficiency. The reflective modulator optics have been redesigned to make better use of the full output from the second-stage amplifier.

The third difficulty again has to do with the use of resistive ballasts which prevent the attainment of optimum gain conditions in the power amplifier. This too will be remedied by the introduction of the electronic ballasts.

Despite these deficiencies, the output measured in the pulse train is approaching the design goal of 1 kW. Figure 18 shows the average output power measured in 10 μ sec pulse trains at 3,000, 6,000 and 12,000 pps. By insertion of an absorber at the output of the second-stage amplifier, the background oscillation of the power amplifier was measured in the absence of a pulse train input. The resultant average power was 350 W. This implies that for the 12,000 pps rate, the pulse train contained at least 900 W. The energy per pulse was therefore on the average $900/12,000$ or 75 mJ. In fact the pulse train output was found to be almost 100 percent modulated so that at the peak of the modulation the wave energy per pulse approached 150 mJ. These figures are to be compared with the 100 mJ pulse output envisioned for the original design.

By adjustment of the modulator lens an output pattern can be seen which measures approximately $1\frac{1}{2} \times 2\frac{1}{2}$ in. at the output of the power amplifier. This is approximately three times larger than to be expected from a diffraction-limited beam. We expect this pattern to be improved with the use of reflective optics.



POWER OUTPUT VERSUS REPETITION RATE FOR TRAINS OF $10\mu\text{sec}$ PULSES.

FIGURE 18

VIII. CONCLUSIONS

Our measurements to date on the prototype radar transmitter indicate that, with a few modifications to the optics and current supplies, the goal of 0.1 J output pulses at a 10 kc pulse repetition rate will be achieved. The rigidity of the entire oscillator and amplifier assembly is adequate to control the output beam to well within the 2×10^{-4} radian angle of a beam limited by diffraction from a 5 cm output aperture. The main thrust of the work remaining to be done on this device will have to do with precise measurements of the spatial form of the output beam, its variation with time and its dependence on the quality, alignment, and temperature variation of the optics. A simple beam-scanning mechanism has been designed for these measurements to give an oscilloscope train of the beam profile as observed in the focal plane of a 12 m mirror. The optics are sufficiently flexible to be adjusted to minimize any axial distortion on the beam; asymmetric distortion, if it occurs, will be more of a problem.

In addition, measurements are to be made of the time dependence of the output beam and its noise spectrum observed and analyzed. Here it will be important to look at pulse-to-pulse stability and at the high-frequency noise which could interfere with use of the instrument as a source for Doppler radar. Depending on the outcome of these observations, we will be able to suggest modifications of the design to further improve performance of the radar system. Life tests of the entire assembly will be made by undertaking a series of measurements of both atmospheric backscatter and high-power propagation experiments in absorptive media. These experiments will allow the equipment to be tested in a semioperational situation wherein propagation into the atmosphere is attempted along with heterodyne detection of the return signals. Part of the equipment is already assembled. Measurements should begin by March 1, 1968.

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Exploratory work on the behavior of dc and pulse excited CO ₂ laser amplifiers has resulted in the design and construction of a prototype laser radar transmitter. It is capable of an output of 1 kW average power in a train of 10 ^μ sec pulses at a pulse repetition rate of 10 kc. This report summarizes the experimental results leading to the final design, outlines the design features and discusses initial tests of the performance of the completed device.			
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